WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Benefits of Various Best Management Practices in Reducing Herbicides in Runoff Water

Focus categories: NPP, WQL, SW

Keywords: Agriculture, Herbicides, Pesticides, Rainfall-Runoff Processes, Runoff, Water Quality, Filter Strips

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Water Problem, Need for Research, etc.

The major factors causing water quality impairment in the Mississippi Delta, one of the most intense agricultural areas in the U.S., arise from movement of water from land surfaces. The rainfall amount and intensities often are high, causing rapid contaminant movement through the ecosystem. Since agrichemical use is high, applications immediately followed by rainfall create a significant probability of their mobilization in the environment. The erosive nature of precipitation to bare soil disperses soil particles. As they travel across the soil surface with runoff, coarser sediments are left behind. What reaches streams and lakes are highly adsorptive colloidal materials that remain suspended for long periods, are pollutants themselves, and are carriers of pollutants. Although a number of laboratory and small-plot studies have developed potential best management practices (BMPs), data are lacking at the watershed scale, particularly in the Mississippi Delta. A Management System Evaluation Area (MSEA) has been established that focuses specifically on BMPs and their effects on production agriculture and oxbow lake quality in the Mississippi Delta, with maximized profitability and minimized environmental impact. BMPs implemented in this project range from low-input (e.g. vegetative filter strips, riparian zones) to high input (no-till or conservation tillage). In some instances we know that these systems work, but at the watershed level do not 1) understand the mechanisms, and 2) understand how multiple BMPs may interact. To develop recommendations that apply to areas outside these watersheds, a fundamental understanding of these issues is imperative.

Expected Results, Benefits, Information, etc.

This research will have two principal thrusts. The first will be to evaluate the effect of a stiff-grass vegetative filter strip composed of switchgrass in conjunction with conventional and conservation tillage systems on off-site movement of two widely used soil-applied herbicides. It will also evaluate this off-site movement over time within a runoff event. Second, laboratory studies will be initiated to determine herbicide adsorption and degradation in the filter strips, the treated fields, and at various intervals moving into the riparian forest at one of the watersheds. This information will benefit the environment, as well as the producer, by determining maximum benefit of filter strips while minimizing the amount of land taken out of production. These results will provide critically needed data on mechanisms which can effectively reduce erosion, thus meeting compliance with federal conservation programs, and concurrently reduce herbicide content in runoff exiting fields. The dual benefits of reduced sediment and herbicide movement, coupled with other advantages associated with clean tillage between the vegetative filters, will present a clear, viable alternative to other conservation programs which reduce erosion but often lead to increased herbicide movement in runoff. Additionally, determining benefits, if any, of linking multiple BMPs (vegetative filter strips and conservation/no-till) will provide invaluable information for modeling purposes, and for recommendations from various governmental agencies.

Nature, Scope, and Objective of Research

The Mississippi Delta is a major crop producing area in the United States, matched only by portions of the Midwest in farming intensity. Due to a humid sub-tropical climate, both insects and weeds have a far greater impact on farming than in most portions of the nation. Similarly, high levels of microbial activity promote oxidation of native soil organic matter, requiring nutrient replenishment through synthetic fertilizers. As a consequence, the intensity of agrichemical use is exceptionally high, particularly in cotton. There is clear evidence that agriculture has had an impact on surface water resources of the region. This was especially true in previous decades with poor soil conservation practices, intensive fertilization, and heavy use of long-lived pesticides such as DDT. Although management practices have changed, many of the impacts continue. The infrastructure has been established to measure how alternative agricultural systems impact water quality and sustainability in Delta farming.

The major factors causing water quality impairment in the Delta center on movement of surface waters. The rainfall amounts and intensities are seasonally high, causing significant contaminant flux through the ecosystem. Since pesticide and fertilizer use is high, unfortunate timing of application allows a significant probability of mobilizing these compounds in the environment. Cotton and soybean farming usually leaves the soil almost completely exposed for several months annually. The nature of normal precipitation events on relatively bare soil disperses soil particles. Thus, they generate sufficient sediment loss to cause environmental problems. What reaches the streams and lakes are highly adsorptive colloidal materials which can stay suspended for extremely long periods. Thus, the system selectively delivers colloidal materials (fines), which are pollutants themselves and are also carriers of other pollutants.

In surface waters, suspended colloids block sunlight, one of the essential factors for production of phytoplankton, the base of the aquatic food chain (Avinmelech et al. 1982; Threlkeld and Soballe 1988). Under these conditions nutrients (e.g. nitrogen and phosphorus) can accumulate so that as waters clear, algal blooms proliferate. The decomposition of dead algae consumes oxygen, selectively killing those species of fish which are most valued for game fishing. Heavy rains also carry fertilizers into streams and lakes, amplifying this process. Depending on the type used, pesticides which have not degraded travel in runoff, either as a solute or adsorbed to suspended particles.

The keys to protecting the surface waters are: 1) to protect the soil from the impact of rain; 2) to reduce the usage of chemicals to just those levels necessary to produce and protect the crop; 3) to slow the movement of runoff sufficiently to allow sediment to settle or be filtered out before it reaches a lake; and 4) to enhance utilization of field edges and riparian zones for contaminant filtration.

Although significant changes in agricultural practices have occurred in recent years, there are several barriers to a broad acceptance of methods for improving the quality of Delta streams and lakes. While a significant amount of laboratory and plot-scale research on best management practices (BMPs) has been conducted, very little information is available for watershed-scale processes. The premier research projects attempting to demonstrate the viability of BMPs at these large scales are Management System Evaluating Area (MSEA) studies. There are five of these projects at present in Midwestern states, stretching as far east as Ohio and as far south as Missouri (USDA-ARS 1993). Generally funded by a combination of USDA-ARS and USDA-CSREES funds, the data from this research are providing guidelines for determining practices acceptable to both producers and enforcement agencies. Importantly, however, these results are not likely to be applicable to farming practices in the southern United States.

Agriculture in the southern United States differs significantly from that of the Midwest. In addition to increased dependence on pesticides, climate and soil differences, the crops and cultural practices dictate a different array of pesticide and nutrient management schemes. Fortunately, the South has many potential BMPs, but both the sources of recommendations and concerns over their utilization have varied, and farm-level testing is sparse. For example, Ducks Unlimited has sponsored broad use of slotted board risers and winter flooding. These allow more settling of eroded sediments and control weeds with reduced pesticide use by creating anaerobic conditions for the weed seed. But, there is little information on the magnitude of their impact on receiving waters or their place in an economical farm management system. Data from potential BMPs developed for southern U.S. farming, though sparse, are in great demand from producers, environmental enforcement agencies, and private interest groups.

The Mississippi Delta is an alluvial plain, typically with low slopes and poor drainage. One of the primary objectives for row crop producers is moving water off fields as quickly as possible. Thus, many are surprised that substantial quantities of sediment, along with nutrients and pesticides, are moving off these fields, and that BMPs are needed to control this movement. However, McDowell (1989) and McDowell et al. (1981) reported movement of sediment and pesticides from these soils. Most troubling in these losses were the high levels of colloidal clays, which tend to remain in suspension much longer and create more water quality degradation than other particulates.

Various BMPs may be optimized for use on these soils. These would include:

Vegetative filter strips. These strips of perennial, non-invasive grasses are typically composed of tall fescue (*Festuca arundinacea*), are 2 to 10 m in width, and are either placed at the turnrow or at intervals in the field. Research in Mississippi has demonstrated their effectiveness in reducing sediment and herbicide loads in runoff water (Murphy and Shaw 1997; Webster and Shaw 1996). Alternative species of tall perennial grasses have also been effective (Rankins et al. 1997).

Reduced- or no-till. Numerous studies have demonstrated that reductions in tillage and/or crop residues on the soil surface will reduce sediment losses (Griffith et al. 1986; Hairston et al. 1984). Less clear is the impact that these systems have on pesticide movement. In some instances moving to a no-till system reduced pesticide movement in runoff while in other instances, sometimes in the same study, increases were noted (Hall et al. 1972; Ritter et al. 1974; Shaw et al. 1992; Webster and Shaw 1996).

Riparian zones. Most of the Mississippi Delta was originally in hardwoods, and there are many areas which remain out of crop production. These often are drainage systems for agricultural fields, and are a rich resource to serve as a natural biological system to selectively filter runoff.

A large-scale project aimed at the study of practices that are environmentally sound, economically effective, and acceptable to Southeastern producers is needed to develop a watershed-level database to validate BMPs and increase their acceptance. In order to address this critical need, a MSEA project has been established in the Mississippi River Delta to address a common goal of agricultural productivity and nonpoint-source concerns for the Southern region.

Many of these BMPs have proven to be effective at the plot level, but many have not been adopted on a widespread basis for various reasons. All of these BMPs will be evaluated at the watershed level in some portion of the proposed MSEA project. This will allow a demonstration of how BMPs developed and tested on a small-plot scale can be utilized at the watershed or regional level. In addition, research at this level can develop accurate and credible economic analyses that further demonstrate the feasibility of these BMPs.

The project is located within three oxbow lake watersheds. These offer an excellent opportunity to thoroughly test management practices tailored to Southeastern crops and cultural preferences. The large number of oxbow lakes in the region allows selection of several similar watersheds. Unlike many watershed studies, data collection need not be limited to groundwater and short-term runoff data; the presence of lakes allow long-term study of the impacts of runoff: short-term losses, impact on quality of lake waters, life span of chemicals, impact on lake ecology, accumulation of pesticides in fish tissue, and changes in sediment quantity and quality.

In reviews conducted by the Natural Resources Conservation Service, they have begun to request more work tying plot-level, field-level, and watershed-level models together more closely. This project offers an unusual opportunity to do so. This will enable other researchers to begin to gain a better sense of the extent to which the various models can be scaled to the watershed level.

These data can be used to educate producers, enforcement agencies, and the public regarding: 1) past and present impacts of agriculture on ecosystems; and 2) the environmental benefits of installing management systems of acceptable cost and wide acceptance. These studies also will expand the number of practices available by generating researchable issues.

The specific objectives of this proposal are: 1) to evaluate the effect of a stiff-grass vegetative filter strip composed of switchgrass in conjunction with conventional and conservation tillage systems on off-site movement of two widely used soil-applied herbicides. It will also evaluate this off-site movement over time within a runoff event. 2) Laboratory studies will be initiated to determine herbicide adsorption and degradation in the filter strips, the treated fields, and at various intervals moving into the riparian forest at one of the watersheds. This will provide an understanding of not only the level to which "filtering" is taking place, but also a more fundamental understanding of the mechanisms of how it takes place.

Methods, Procedures, and Facilities

The proposed runoff plot research will be conducted at the Black Belt Branch Experiment Station near Brooksville, MS on established standard USLE (4 m by 22 m) soil erosion plots. Previous studies have indicated that these plots are of sufficient size to estimate losses from watersheds with similar characteristics (Burgoa and Wauchope 1992). Soils at the Black Belt Station are silty clay with high smectitic properties and low slopes, similar to the Sharkey clays of the Delta. These plots are already established and instrumented, thus enabling initiation of the project without excessive cost. Plots are bordered with a metal strip to exclude outside runoff, and each plot is equipped with a 15 cm H-type flume. Two factors will be evaluated in a factorial design, tillage system (conventional tillage, conservation tillage, and no-till planting into a wheat cover crop) and presence or absence of a switchgrass filter strip. Switchgrass will be placed at the base of the plot when needed.

Cotton will be planted into each system, and norflurazon and fluometuron, each at 1.68 kg ai/ha, will be applied to all plots. Plots will be maintained free of weeds throughout the duration of the growing season by hand hoeing as necessary.

A rainfall simulator with an output of 2.5 cm per hour will be used to supplement natural rainfall in order to guarantee a minimum of 5 cm of rainfall at 2-week intervals for a total of 10 weeks. All runoff will be collected from each plot and quantified. Within each runoff event, samples will be collected at five-minute intervals from the initiation of runoff to the conclusion of the runoff event in order to describe herbicide losses both across and within these runoff events. Composite samples will then be obtained and stored at 2 C. Subsequent to the final runoff event, all samples collected will be analyzed by the researcher using appropriate analytical methodology. Norflurazon and fluometuron residues will be determined with a lower detection limit of 250 parts per trillion (ppt) and 100 ppt, respectively. These concentration values will then be combined with the total runoff from the plot in order to determine total herbicide loss at each runoff event on a per hectare basis, and subsequently total yearly loss due to off-site movement in surface runoff. Regression analysis will be used to describe loss patterns across the various combinations of filter strips and tillage systems.

Fluometuron adsorption studies will be conducted on soil collected from different sites within one of the MD-MSEA watersheds. Soil samples will be collected from environments influenced by a established grass filter strip (S_{est} >5 yr), new grass filter strip (S_{new} 1 yr), and riparian forest (R). These BMPs will be compared in combination with watershed tillage practices. Soil samples will be characterized for organic matter, clay type and content, pH, texture, and sum of exchangeable cations by previously mentioned procedures. An adsorption study will be conducted to evaluate soil constituents for their ability to retain and / or be potential carriers of fluometuron in runoff water.

Batch techniques will be used to characterize fluometuron sorption kinetics. Eighteen samples (4 S_{est}, 4 S_{new}, and 10 R) will receive four different fluometuron concentrations with three replications yields a total of 216 samples. Concentrations of 0, 0.01, 1, 4, and 8 *F*g ml^{-1} that contain 0.045 *F* Ci ml^{-1} uniformly ring labeled ^{14}C-fluometuron will be dissolved in a 0.01 *M* $CaCl_2$ solution. Sample suspensions will be prepared by the addition of 5.0g air dried soil into 25-ml centrifuge tubes followed by adding 10 ml of 0.01 *M* $CaCl_2$ solution (10). The sample suspensions will be shaken for 15 hours to attain equilibrium. After the appropriate shaking time is achieved, samples will be centrifuged and 1 ml aliquots of supernate will be added to a 15 ml water-accepting scintillation cocktail. Liquid scintillation spectrometry will be used to count ^{14}C radioactivity for each sample (10). Adsorption isotherm models will be developed using Freundlich parameters (K_f and [1/n]) calculated via linear regression of log transformed data. Fluometuron adsorption to soil will be evaluated for correlation to soil properties.

Data derived from field and laboratory research in this project will be correlated to data generated from the various watersheds in the MD-MSEA project. Sampling sites within the three watersheds are focusing on runoff water from conventional-tillage and conservation-tillage systems, prior to and after vegetative filter strips, and prior to and after passing through a riparian forest. Modeling efforts planned for the MD-MSEA project will use the watershed-level data for model validation and refinement. Data generated in this research will be useful to understand underlying mechanisms of herbicide reductions effected by various BMPs that are evaluated.

The principal investigator will organize and supervise the studies described, and will spend approximately 10% of his time on this project. The co-principal investigator will supervise the laboratory analyses and method development, and will also spend approximately 10% of his time on this project. The graduate research assistant will assist in organization, collection, and analysis of the data, and will use this research in partial fulfillment of a Ph.D. dissertation research project. Graduate research assistants and part-time employees will also be involved in rainfall simulation and sample collection. An analytical research assistant under the supervision of the principal investigator will be responsible for extraction and analysis of all samples. Black Belt Branch Experiment Station personnel will be involved in maintenance of the runoff plots.

Related Research

Water erosion removes 1.5 to 2 billion tons of U.S. topsoil each year, and is a significant problem nationally. The Mississippi River alone carries 331 million tons of sediment to the Gulf of Mexico annually (Brown 1984). Fowler and Heady (1981) reported that suspended sediments are, by volume, the largest pollutants in the United States. Delta lakes, long known for their biological productivity and recreational value (Cooper et al. 1984), have not escaped the detrimental effects of soil erosion. Their popularity as recreational resources has decreased as water quality and fisheries have declined (Coleman 1969). Cooper and Knight (1978) have attributed these declines, in part, to soil erosion, sedimentation, and pesticide contamination. While most fish tolerate a maximum long term concentration of 80 to 100 mg/L of suspended solids (Wedemeyer et al. 1976), lower levels would constitute optimal conditions.

Most agricultural pollutants move with water. Water provides the vehicle and energy to solubilize and transport agrichemicals, and erode and transport particles. Lowering the kinetic energy of moving water results in reduced erosion and transport of non-point source pollutants. BMPs in farming systems are designed to control the movement of water and consequently reduce loss to surface waters of agricultural pollutants such as pesticides, nutrients, and sediments. Most BMPs have been developed and evaluated in plot studies but have not been effectively evaluated on a watershed scale.

MSEAs are specifically designed to test management practices on the farm scale. There is a consensus at the policy level that nonpoint-source pollution should receive heightened attention in the near future (U.S. EPA 1994a; 1994b; 1994c) . In general, agencies are adopting the concept of BMPs as the preferred method of determining compliance with nonpoint-source pollution abatement programs. The most preeminent studies on effectiveness of BMPs are the existing MSEA projects (USDA-ARS 1993). No study of equivalent scale exists for the dominant crops, chemicals, and cultural practices of the southeastern United States.

Oxbow lakes are remnants of meandering floodplain rivers which have been cut off and physically isolated (at least seasonally) from their respective main river channels. If seasonal connections to the rivers are maintained through flooding, oxbow lakes are driven functionally by heterotrophic processes dependent upon the interactions between aquatic and terrestrial environments (Goulding 1980; Insaurralde 1992) and the introduction of allochthonous organic materials (Junk et al. 1989; Benke et al. 1985). Flooding stimulates both detrital processing and primary production within inundated terrestrial components of the ecosystem (Bayley 1989). These dynamics in turn establish the energetic foundation supporting secondary production and ultimately the fish production potentials associated with the ecosystem. The extent and duration of flooding strongly influences fish production (Welcomme 1976, 1979, 1985, 1986; Goulding 1980) because fish utilize floodplains (including oxbow lakes) as spawning grounds, food sources, and refuges (Risotto and Turner 1985).

If suspended sediment concentrations are low enough to provide suitable light penetration, oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support sustainable sport fisheries. However, agricultural practices often result in erosion and transport of sediments to lakes, which can lead to increased turbidity and subsequent inhibition of photosynthesis. Turbidity in oxbow lakes can be persistent in areas having soils with high clay content. Also, while nutrients such as phosphorus are commonly associated with Delta soil loss and load lakes with these nutrients, these systems may be energy deficient due to lack of light penetration, and therefore unproductive.

In shallow lakes, such as the oxbows in the MD-MSEA project, the primary site of organic matter decomposition may be the bottom sediments rather than in the water column (Capone and Keine 1988). Small oxbow lakes receiving a high loading of nutrients, mineral particles, and organic matter from the land surfaces have limited ability to utilize solar energy in photosynthesis and tend to be dominated by heterotrophic metabolism. At the sediment surface of these lakes, where contact of the water with the atmosphere is limited through stratification and organic matter tends to accumulate due to sedimentation, oxygen consumed in respiratory processes may decline to low levels or be depleted entirely during part of the year. Degradation of organic matter, which in Mississippi Delta oxbow lakes may include high concentrations of synthetic agrichemicals, does not occur as efficiently or as rapidly by anaerobic metabolic pathways as by aerobic decomposition (Brock et al. 1994). Consequently, a lake adjacent to a poorly managed agricultural field may have low primary productivity due to mineral turbidity, a low oxygen concentration above the sediments for at least part of the year, relatively slow rates of organic matter decomposition, and ultimately a shortened life span.

Pesticides and nutrients serve as significant contaminants of surface waters in many areas of the United States. A recent survey of nonpoint-source contaminants in the Mississippi River and its tributaries found concentrations of fluometuron, one of the most prominent cotton herbicides, as high as 411 ppt during July and August in the lower Mississippi River and three of its tributaries, the White River, Arkansas River, and Yazoo River (Pereira and Hostettler 1993). A similar study in 1990 estimated that as much as 18 metric tons of fluometuron was discharged into the Gulf of Mexico each year (Pereira and Rostad 1990). Surface water eutrophication has been observed in the Delta. This is the direct result of excessive nutrient concentrations from runoff of agricultural fields (McDowell 1989). Therefore, substantial quantities of cotton nutrients and herbicides are moving away from the point of application, causing concern from an environmental standpoint. Measures are needed to minimize these occurrences. A number of soil factors can influence the fate of herbicides and nutrients, including texture, organic matter, cation exchange capacity, and tillage practices (Harrison et al. 1976; Nelson et al. 1983).

Slopes in the Mississippi Delta are flat (sometimes land-formed), often less than one percent. Despite this flat topography, the erosivity of Delta soils coupled with little cover and low residue from cotton can produce soil loss rates as high as 10 tons/acre per year or more (NRCS Greenwood, MS). This rate of loss is higher than tolerance rates of 5 tons/acre per year for typical soils in the Delta. Therefore, erosion control is central to a program of Delta BMPs.

Most of the eroded sediment is detached by raindrop impact. Sediment particle sizes cover a wide range of values. On flattened slopes, coarser sediment settles out of runoff water before reaching the edge of the field. That which reaches the edge of the field is much finer and can have a much greater impact on water quality in the lakes than coarse sediment. Fine sediment stays in suspension much longer than does coarse sediment, and the fine material is a pollutant itself, serves as a carrier for pesticides and nutrients, and limits light. Also, the fine sediment has tremendous specific surface area and can retain a much higher percentage of contaminants per unit weight than can coarse sediment.

A major challenge is the level to which fine sediment reaching the lake must be reduced. Either erosion rates will have to be reduced to less than soil loss tolerance or a very high percent of the sediment in transport will have to be trapped at the edge of the field. Reduction of the sediment loss by trapping with grass strips at the edge of fields may not be sufficient. The trapping efficiency of grass traps or other practices that reduce sediment load to lakes by inducing deposition is not high for colloidal or fine particles. Thus, the trapping efficiency of grass strips is likely to be much lower when used in the Delta than for soils where large-sized particles are being transported in runoff.

The Universal Soil Loss Equation (USLE) has been the principal means for developing conservation plans to control erosion and conserve soil resources. It is now being updated with the Revised Universal Soil Loss Equation (RUSLE), which has improvements in it that highly relevant to the MD-MSEA study. The calculations for cover-management effects and the slope steepness factor have been validated with data collected in the Mississippi Delta and nearby upland areas. An important computer program has recently been released that combines RUSLE for computing soil loss, computation of loss of nutrients and pesticides from fields, and farm economic calculations. This program, PLANETOR, is a helpful tool for strategic, whole farm planning that includes environmental factors (Foster 1995).

While RUSLE is much improved and is adequate for computing within-field erosion rates, it cannot be used to estimate sediment transport to the edge of the field or from the field. Other models such as GLEAMS, for field-scale, and AGNPS, for watershed applications, are superior to RUSLE for computing sediment delivery to the lakes. These models have transport components that are absent in RUSLE. These components take into account processes leading to colloidal-size particles in runoff and provide estimates of the effect of sediment particle size on the transport of contaminants. Both of these models utilize portions of USLE, which must be updated to RUSLE for use in the MD-MSEA study. The same is true of other water quality models that use USLE relationships such as EPIC and SWAT (Foster 1995).

Movement of sediments from eroded soils have been modeled by the USLE, but many questions have arisen regarding the accuracy of the factor for management practices, particularly more recent ones. Few of these have been answered even by the revised version of the model, RUSLE (Renard et al. 1991). The models most commonly cited as preferred predictors of pesticide movement are GLEAMS and PRZM (Mueller et al. 1992; Pennel et al. 1990; Smith, et al. 1990). Despite these data, many factors are still being calibrated by new field studies. Although not commonly associated with nutrient movement out of the plant area, researchers have noted the potential use of plant growth models for predictive purposes (Murphy 1991).